Federal Aviation Administration, ADS-B Program Office
Broadcast Services Ground System Specification Team
Meeting #16
L-3 / The Titan Group, 400 Virginia Avenue SW, Washington DC
25 – 27 April 2006

A Proposed Algorithm to Handle Duplicate Mode S Addresses in the BSGS 1090ES Time Registration Function

In response to Action Item 15-3

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SUMMARY

This Working Paper proposes an algorithm to deal with the potential problem of aircraft having duplicate Mode S addresses occurring within the coverage of a given BSGS ground station.

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March 27, 2006

1.0 Statement of the Problem

This Working Paper proposes an algorithm to deal with the potential problem of aircraft having duplicate Mode S addresses occurring within the coverage of a given BSGS ground station. As was pointed out in industry comments to the current BSGS specification draft, the current design of the BSGS 1090ES Time Registration function algorithm depends on the uniqueness of Mode S addresses to properly combine ADS-B 1090ES airborne position and velocity ADS-B messages into a consistent state vector output. The algorithm will produce erratic (and possibly erroneous) outputs if more than one aircraft in coverage has a given Mode S address. While this situation has become very rare over time, it is still possible and may occur at any time – whether by error or by malicious intent. This Working Paper describes how the BSGS processing algorithms may be extended to deal with the duplicate-address situation. It will be shown that the proposed algorithm is a modest addition to the existing software functionality already defined in the BSGS draft specification.

2.0 Proposed Algorithm Description

The proposed duplicate-address track-handling algorithm described in this paper is built on the BSGS 1090ES Time Registration function (a.k.a the Kalman Filter) and its outlier test as described in section 3.2.3.2.1.1.2.3 of the current BSGS draft specification (as modified by the changes defined in paper BSGS15-WP03 "Revised Outlier Test for the time Registration Function"). The proposed duplicate-address track-handling algorithm starts with the assumption that a given aircraft system "state vector" (i.e., "track") T_1 already exists. ADS-B 1090ES messages for a new aircraft having the same Mode S address as T_1 now start appearing at the BSGS. Since the new aircraft is not at the same location as T_1, it is assumed that its ADS-B messages will be declared outliers by the processing defined for T_1. These T_1 outlier messages form the inputs to the proposed algorithm.

The proposed duplicate-address track-handling algorithm assumes that a secondary set of state vector data structures (tracks) is available in the BSGS software to deal with duplicate address cases. These tracks will be processed in a similar manner to the primary tracks (as defined in the current BSGS draft specification) except as noted below in this paper. Only those ADS-B 1090ES messages that are declared outliers during processing of their primary track entry will be further processed against their secondary track entries.

The proposed duplicate-address track-handling algorithm assumes that each BSGS state vector (track) data structure contains two new elements beyond those already defined in the BSGS draft specification. These new elements provide for the linking of BSGS track structures to each other to form linked-lists. One new element is termed the "forward link". This track pointer allows the duplicate-address algorithm to find those secondary track(s) having the same address as the primary or current secondary track. (This linked-list mechanism allows for more than one duplicate address to be handled.) The second new element is termed the "backward link". As its name implies, this pointer goes in the reverse direction – allowing secondary tracks to find their primary track with the same address. Both the forward and backward track links are initially set to 'null' (no linked track) in the normal case (no duplicate-address track for this Mode S address as yet). The further use of these track links will be described below.

2.1 Duplicate Track Initiation

As mentioned above, outlier ADS-B 1090ES messages from the processing of track T_1 are candidates for the initiation of a secondary track (with a duplicate address to T_1). Note that true outlier points will be very rare in the normal case – they would result from uncorrected decoding errors in the message processing or in the avionics of the aircraft. Consistent and frequent outliers for a given track suggest a duplicate-addressed aircraft. Hence, the algorithm for initiation of a duplicate-address track looks for consistency and repetition among T_1 outlier messages.

Note: the duplicate-address algorithm processing described in this section assumes that T_1 does not already have a duplicate-address track. The algorithm would determine this by looking at the forward link entry in the state vector for T_1. In the normal case (no duplicate-address track to T_1), T_1's forward link would be null (no track). If T_1's forward link is not set to null (indicating that T_1 has a duplicate-address track in the system), then the duplicate-address algorithm would perform the track update function as described in section 2.2 below.

The proposed duplicate-address track-handling algorithm initiates secondary 1090ES tracks using the same process as for track initiation of normal 1090ES BSGS tracks. Two 1090ES ADS-B position input messages, one with even-format and another with odd-format, that are both declared as T_1 outliers must occur within parameter P1 (suggested value 10 seconds – the same value used to initiate normal tracks in the BSGS) of each other. The "Compact Position Reporting" (CPR) global decoding algorithm is applied to the pair of input messages to obtain an initial track position value for the duplicate-address track (denoted T_2).

If the T_1 outlier messages fail the track initiation test described in the preceding paragraph, then they are simply the usual (rare) outlier case and no further processing is done. If the track initiation tests are passed, then a new secondary state vector is initiated (denoted T_2) using the even and odd-format position messages in the manner defined for normal tracks in the BSGS specification. The forward link of T_1 is set to point to T_2, and

the backward pointer of T_2 is set to point to T_1. The number of outlier messages for T_1 is decremented, since it has been determined that these messages were from an aircraft with a duplicate-address – not true outliers.

It should be noted that the duplicate-address track initiation algorithm described in this section will be triggered in two possible cases: (a) when there are two or more actual aircraft with the same Mode S address in the coverage volume, and (b) when the single track on a given aircraft is being dropped due to a sequence of outliers (the result of an extreme aircraft maneuver beyond the capability of the BSGS 1090ES Kalman Filter to maintain the track on the aircraft). The track drop will be caused by a parametric number (3 or more) of consecutive outlier messages for the given Mode S address (see section 2.3 below). Since it may only take two position outlier messages to initiate the duplicate-address track, the duplicate-address track may initiate before the original track is dropped. Hence, the BSGS can produce fully tracked output on the given aircraft using the new track without incurring additional track initiation delay.

2.2 Duplicate Track Update

As mentioned in section 2.1 above, processing of a given ADS-B 1090ES message starts with the BSGS Time Registration function as defined in the BSGS specification. If the message is flagged as an outlier for T_1, then the outlier message is available to either update an existing duplicate-address track (if one exists for this address) or to potentially initiate a new duplicate-address track (as described in section 2.1 above). If the primary track entry for this address (T_1) has no forward link track, then processing goes immediately to duplicate-address track initiation as described in section 2.1 above). If T_1 has a forward link track (denoted T_2), then the proposed duplicate-address track-handling algorithm first attempts to update T_2 using the input message.

The update processing for T_2 is identical to that defined for T_1 in the BSGS specification. If the input message passes the outlier test with T_2, then the updated state vector for T_2 is output and the outlier count for T_1 is decremented. If the outlier test for the message with T_2 fails, then the algorithm checks the forward link entry for T_2. If T_2's forward link is null, then the message fails to update any track and becomes an input to the track initiation processing described in section 2.1 above. If T_2's forward link is not null, then the algorithm processing continues with the linked track (T_3), etc. By following the forward links until a null link is found, any number of duplicate-address tracks may be dealt with by the proposed algorithm.

Note that if the input message succeeds in updating any track along the list, then all previous tracks on the list must have their outlier counts decremented. These tracks are found by following the back link entries until a null link is found (this will be the initial track with this address T_1).

It should be noted that, in the rare case where the velocities of the original and duplicate-address tracks are nearly the same (i.e., the 1090ES ADS-B Velocity Messages for both aircraft pass the outlier test for both tracks), only the original track would receive velocity updates. There would be no outlier messages available to update the duplicate-address track. The velocity output for the original track would be degraded somewhat (since it is using 1090ES ADS-B Velocity Messages from the duplicate-address aircraft as well as from the correct aircraft), while the velocity for the duplicate-address track would only receive position updates. Normal velocity updates would resume once the aircraft tracks diverge.

2.3 Duplicate Track Drop

Duplicate-address tracks are removed from the system using the same rules that are defined for normal tracks in the BSGS specification. A track is dropped when either (a) the track has not been updated in 120 seconds), or (b) the track has seen parameter M consecutive outlier messages. (The nominal value '3' is suggested for parameter 'M'.) When a track is dropped, the forward and backward linkages for this track's address are modified to repair the track lists. The repaired track linkages when duplicate-address track 'T' is dropped may be expressed in pseudo-code as follows.

(T.back).forward = (T.forward)
(T.forward).back = (T.back)

3.0 Summary

This Working Paper has defined an extension to the current BSGS 1090ES Time Registration function specification that provides full support for cases where aircraft with duplicated Mode S addresses occur within the coverage of a given BSGS station. Rather than pass the messages for the duplicate-address aircraft on to BSGS users lacking the benefits of properly formed state vectors, the proposed algorithm would output complete state vectors for all aircraft in coverage of the BSGS station – even in the case of duplicated Mode S addresses.

It should be noted that although this paper has described an algorithm for the 1090ES ADS-B link, equivalent logic would work to deal with address duplication for the UAT ADS-B link. While the UAT link does not need to build a State Vector from independent Position and Velocity Messages, it might still be useful for the BSGS processing of UAT to deal with potential error cases and duplicated UAT addresses.

The issue of handling duplicate address tracks would also impact the output of BSGS track State Vectors. Currently, the proposed ASTERIX Category 33 format does not provide a means to indicate address duplication. There are several approaches to this issue.

(a) Leave the problem of dealing with BSGS outputs having the same address to the user of the data. The user application would need to perform some sort of tracking or consistency-checking algorithm in order to determine that more than one aircraft in coverage is reporting the same address from a given BSGS source.

(b) Add a “duplicate address” flag to the definition of the BSGS output format in ASTERIX Category 33. This flag would be set whenever a BSGS track entry has either a forward or backward link that is not defaulted to null. The flag would alert the user of the BSGS data that this address occurs for more than one aircraft in the coverage region.

(c) Add a “track number” field to the definition of the BSGS output format in ASTERIX Category 33. This track number would uniquely identify each BSGS output track independently from its address. (Note: this is the mechanism used in the ASTERIX Category 48 outputs of radar sensors. Category 48 reports include a 12-bit track number field.)